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## Evaluation of the productivity for new design single slope solar still at different saltwater depth

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**Abstract.** The solar still's productivity affected by various conditions such as design, operational and environmental conditions. The current study aims to investigate the effect of water depth on the suggested solar still productivity. The results showed that the productivity decreased with increasing the basin water depth from 1 cm to 3 cm, and the higher freshwater productivity obtained at lower water depth. It is found that the productivity of solar still at 1 cm water depth started early in comparison with the other two depths (2 and 3 cm), the highest distillate for the three perfect days it was recorded with the lowest water depth of 1 cm, while the lowest distillate was with the largest depth 3 cm. Accumulated distillate during 10 hours from 8:00 am to 18:00 pm was 1.6, 1.35 and 1.05 L/m<sup>2</sup>, for three perfect days 20, 22 and 24.03.2019 and for the three water depths 1, 2 and 3 cm, respectively. The estimated production cost of one liter of freshwater from single slope solar still model found to be 0.033 \$, 0.041 and 0.05 \$ with 1, 2 and 3 cm water depths respectively.

### 1. Introduction

One of the biggest problems in the world is water scarcity. Though water scarcity isn't a problem in many world regions, but it is directly affect hundreds of millions of people in their life. One reason for the potable water scarcity is the industry growth and the rapid population growth around the world. For that, the ability to supply a potable water becomes one of the main important problems for a human in arid remote areas [1]. To get a potable water, a power source is required, especially when used to heat brackish water to vaporization degree, condense water vapor, and get freshwater (desalination process). Most large desalination plants around the world use fossil fuels (such as coal, oil, and natural gas) as an energy source to heat and vaporize the seawater or brackish. These sources are not sustainable and limited, moreover, has side effects on the environment in comparison with renewable energy sources such as solar energy. There are many techniques used to convert brackish and seawater into freshwater [2]. Desalination techniques are classified into two groups, the first group is called membrane technology, which includes reverse osmosis desalination (RO) and electrodialysis desalination (ED) [3]. The second group is called phase-change processes or thermal technologies which include multistage flash desalination (MSF) [4], multi-effect boiling desalination (MEB) [5], vapour compression [6], freezing desalination [7], humidification-dehumidification desalination (HDH) [8], combining an outdoor solar heater with an improved solar distillation [9], use a latent heat material such as paraffin wax within solar still [10]. The solar



distillation technology divided into passive and active types. The passive solar system does not include any mechanical devices or any of conventional energy sources [11]. Active solar systems use external energy sources to operate equipment such as blowers, pumps, etc. [12]. The solar water distiller working principle is simple and like the mechanism of rain in nature, the solar radiation heats and evaporates basin water within solar still, when water vapour temperature reduced, the latter returns to the liquid phase. This process leads to the removal of impurities such as salts and other heavy metals and at the end of the process we get pure water [13]. The limited productivity of traditional solar distilleries is one of the most important factors that affect its wide use in various life applications, therefore, there are many studies attempted to enhance the productivity of solar distillers by controlling the design or operation parameters. Among the design parameters that have a clear impact on raising productivity solar still without adding additional components or costs that are the basin water depth, studies were conducted to find out the effect of change water depth on evaporative mass transfer coefficient and coefficients heat transfer for conventional single slope solar distillation, this studies have been conducted during different days for different water depths, for each day a certain water depth was tested. Also from this studies concluded that is at a low depth was the highest productivity and efficiency, and the changes in the value of the coefficients of heat transfer by occur with a decrease in the water depth, while they are approximately constant with an increase in the water depth [14]–[16].

A passive single slope solar still model has been done by a lot of studies, but a few of these studies touched upon the effect of the water basin depth on the performance and productivity of solar distillery. The current study describes an attempt to implement the best suitable water depth to achieve maximum freshwater productivity for three different water depths by using a new design single slope solar still at a lower cost, more efficiency, easy to install and carry, especially in rural and remote areas.

## 2. Methodology of Experimental

### 2.1. Fabrication of solar still:

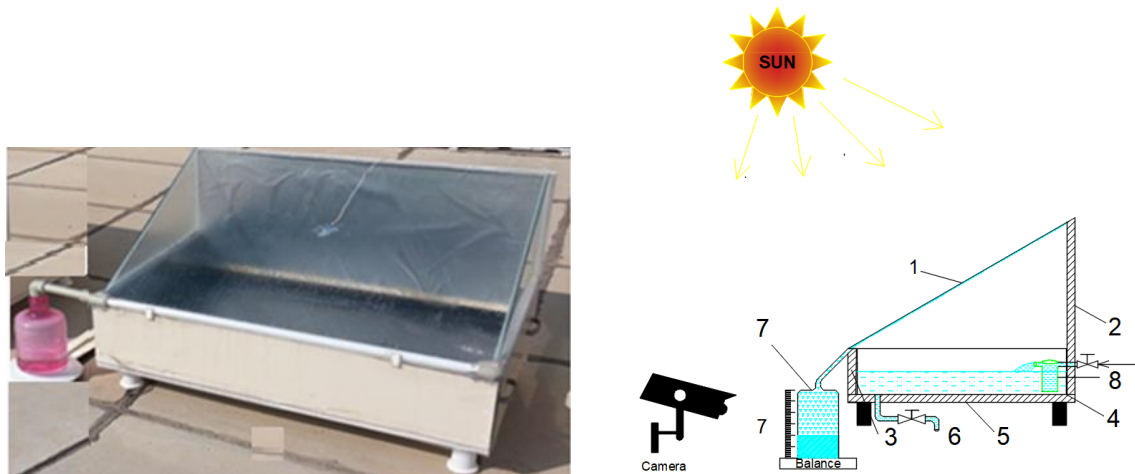
A simple modification in distiller design was performed without extra expensive components and additional space. Figure 1 shows a schematic diagram of the experimental setup of single slope solar still with dimensions of 100 \* 50 \* 40 \* 10 cm (length, width, big side height, and small side height respectively) with wooden structure (MDF) thickness (1.8 cm), consists of wooden frame of dimensions 100 \* 50 \* 10 \* 1.8 cm (length, width, height, and thickness respectively) and MDF wooden board 100 \* 30 \* 1.8 cm (width, height, and thickness respectively) in the backside of solar still. A glass cover of dimensions 100 \* 58 \* 30 \* 0.4 cm (length, width, height, and thickness respectively) fixed on the top of the solar still and inclined 30 degrees. The water basin made of Aluminium plate with a dimension of 96 \* 46 \* 5 \* 0.09 cm (length, width, height, and thickness respectively) has been coated with black colour to absorb maximum amount of solar radiation. The basin was installed on the wooden MDF base of the solar still with dimensions of 100 \* 50 \* 1.8 cm (length, width, and thickness respectively). The inner surface of solar still covered by Aluminium foil with 0.03 cm thickness. Glass cover fixed on the wooden frame by using a PVC channel to collect condensed water droplets on the glass cover, then it passes through the PVC channel to a plastic tank installed at the bottom of the solar still. All parts are fixed by silicone glue to prevent air leakage. A water tank is connected to the solar still via pipes to feed the solar still with seawater. The level of salt-water inside has been controlled by using a mechanical floater, to clean basin liner, a hole was made at the bottom of the water basin and with a globe valve. The new design gives simplicity in periodical maintenance such as clean the glass cover, and basin liner from impurities and salt deposits, easy to carry to other places, especially in remote and rural areas.

## 2.2. Experimental procedures.

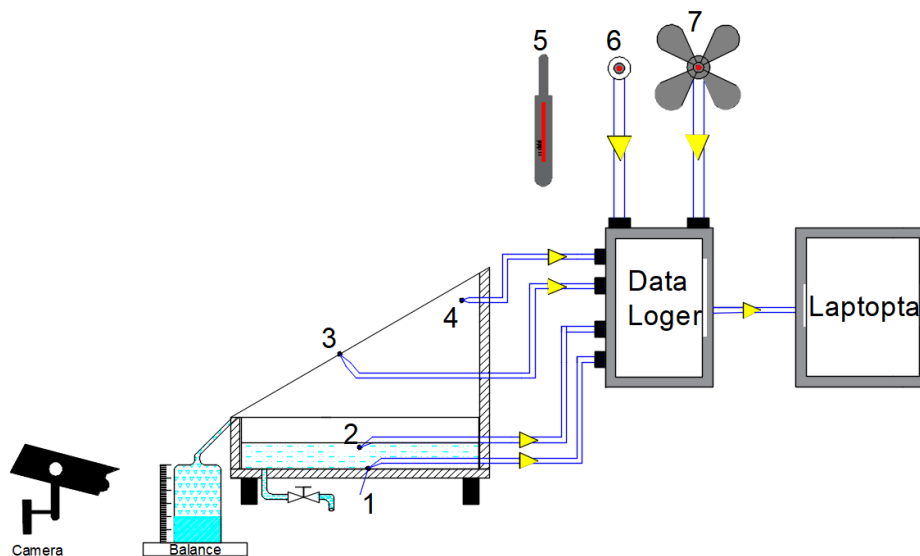
The current study has been applied on new design solar still, all tests started at 08:00 am, to 6:00 pm for one day, during March 2019 on different three days 20, 22 and 24 March and according to Kirkuk / Iraq city climate for different water depth (1, 2 and 3 cm), in each one-day water depth has been used. The solar still was directed to the south direction, and recorded hourly the following parameters:

- Glass cover temperature, vapour temperature within the solar still, basin saltwater temperature, basin liner temperature, and ambient air temperature.
- Wind speed has been measured hourly and gets the average for one day.
- Hourly Productivity ( $L/m^2 \cdot hr$ ) and cumulative production ( $L/m^2$ ).

To measure the temperatures at different points of the solar still such as basin liner (1), basin water (2), vapour temperature within solar still (3), glass cover (4) LCD digital K type 0.3 mm diameter thermocouple thermometer controll 4 channel diameter has been used. The mercurial thermometer has been used to measure the ambient temperature (5). To measure the solar radiation intensity a solar power meter device (TES-1333) has been used (6). Anemometer model DA-40 device has been used to measure the wind speed (7) as shown in fig 2.



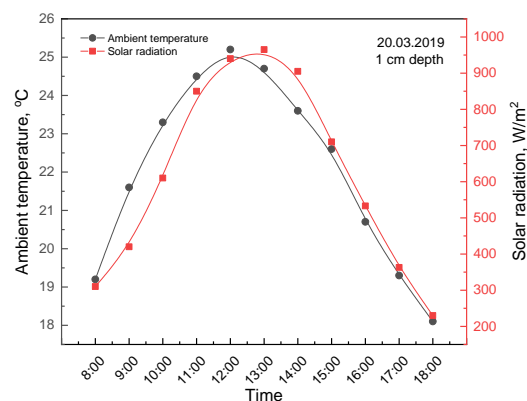
**Figure 1.** Schematic diagram of the experimental setup of the solar still. 1- Glass; 2- MDF basin wooden; 3- Wooden frame; 4- Basin water; 5- Base; 6- Drain; 7- Plastic water collection tank; 8- Floater mechanical



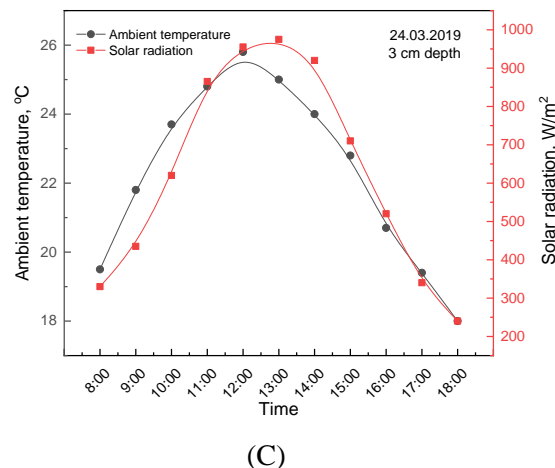
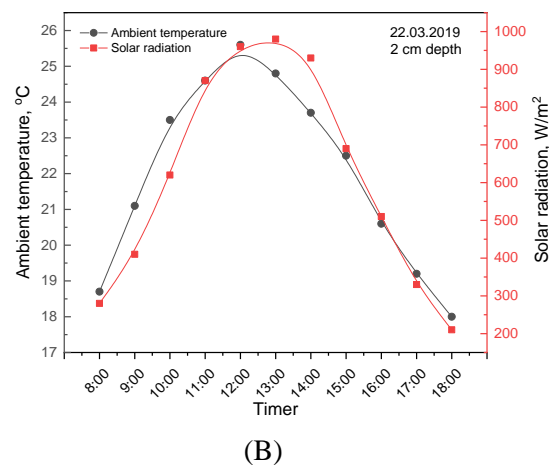
**Figure 2.** Schematic diagram of the measuring devices

### 3. Results and discussion

Figure 3 shows the experiment result, which carried out for three perfect days 20, 22 and 24 March 2019. In the current study, the hourly solar radiation intensity considered to investigate the relation between solar radiation and the standard local time. This figure shows the gradual increase in the solar radiation intensity from the early morning after 8:00 am, until the highest value in the period between 12 -1 pm to reach (965, 980 and 975  $W / m^2$ ) for three days 20, 22 and 24.03.2019, respectively, and gradually decreases after 1 pm until the end of the sunrise at 18:00. After the sunrise in the morning, the sun's rays transfer the thermal energy to the surrounding areas on the earth's surface such as ambient air [13], so that the maximum ambient temperature occurs around 12: 00-13: 00 pm. Figure 3 illustrated the direct relationship between solar radiation and the ambient air temperature for three ideal days. during the period between 12:00 to 1:00 pm, it reached during this period, for the three perfect days 25.2 °C, 25.6 °C and 25.8 °C respectively.

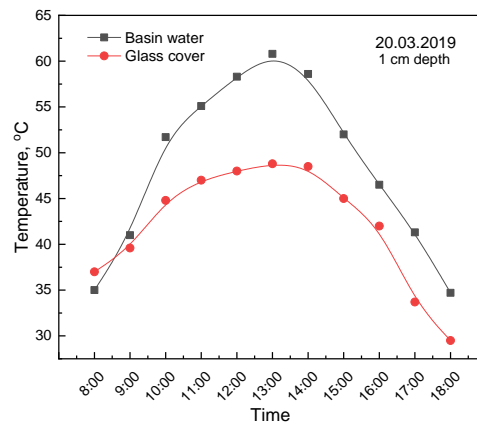


(A)

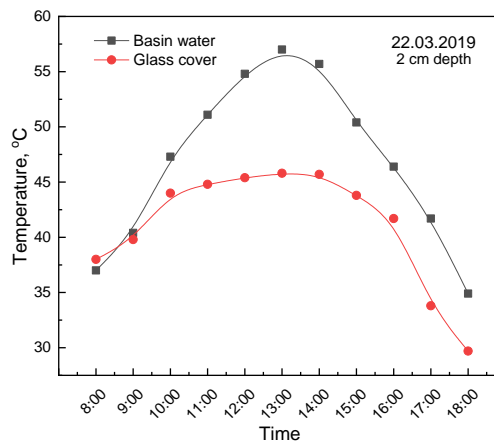


**Figure 3.** The relation between the time per each hour and solar radiation, ambient temperature for perfect days of (A) 20, (B) 22 and (C) 24 March 2019

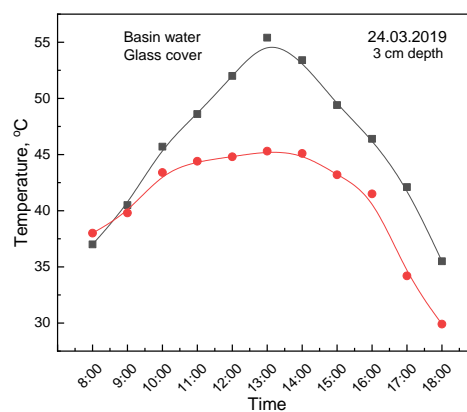
Figure 4 illustrates the hourly variation of basin water temperatures and glass cover during for three different water depths during three perfect days. From this figure, it can be seen that the basin water temperature and glass cover temperature was effected by the environmental conditions such as solar radiation and ambient temperature, but the most influencing factor on the basin water temperature was depth it in the basin, observed during sunrise hours when the water depth decreased from 3 cm to 1 cm, the basin water temperature increased, and vice versa at sunset hours, this is because as the depth decreases, the basin water needs less time to raise its temperatures, therefore, the temperatures difference between the basin water and the cover glass surface on the 22 March with a depth of 1 cm was greater than for the next two days with a depth of 2 and 3 cm during sunrise hours, while after 17:00 the solar radiation intensity begins to decrease, Therefore, the temperature difference decreases with decreasing the water decreasing from 3 to 1 cm, because the basin water temperature in depths 2 and 3 becomes greater than of the depth 1 cm. It was also observed that the glass temperature in the early morning hours exceeded the basin water temperature because the heat capacity of the water is greater than the glass, so, it takes more time for the basin water to raise its temperature. The highest average temperature difference during 10 hours between the glass cover and basin water for three different depths 1, 2 and 3 cm was 6.5 °C, 5.8 °C, and 5.1 °C, respectively.



(A)



(B)



(C)

**Figure 4.** The relation between the time per each hour and temperatures of basin water and glass cover surface for perfect days of (A) 20, (B) 22 and (C) 24 March 2019

Figure 5 shows that the highest productivity of the solar still occurs at the lowest depth of 1 cm. It was concluded that when the basin water depth increased from 1 cm to 3 cm, the productivity decreased. This corresponds to what the researchers stated [17]–[21]. The lower water depth, the higher the freshwater productivity. As a result, the basin water temperature at depth 1 cm decreases, which in turn reduces the water evaporation rate. Therefore, freshwater production decreases with increases the water depth from from 1 cm to 3 cm during sunrise, while the opposite occurs so that it increases at sunset times with increases the water depth from from 1 cm to 3 cm.

When the water depth increased from 1 cm to 2 cm, the productivity ratio decreased by 18%, and it decreased by 28% when the water depth increased from 2 to 3 cm. However, the higher waters depth has a positive effect on productivity when the solar radiation intensity decreases.

From Figure 5-A it was observed that the highest hourly productivity during sunrise times was recorded with the lowest water depths, which was at 13:00 to reach 0.35, 0.325 and 0.3 L / m<sup>2</sup>.hr for three water depths 1, 2 and 3, respectively. Whereas after 16:00, the opposite occurred with decrease the solar radiation intensity, were 0.05, 0.06 and 0.07 L / m<sup>2</sup>.hr for the three water depths 1, 2 and 3, respectively, and at the end of the day 18:00, it reached 0.03, 0.032 and 0.045 L / m<sup>2</sup>.hr. for the three water depths 1, 2 and 3, respectively.

The highest distillate for the three perfect days it was recorded with the lowest water depth of 1 cm, while the lowest distillate was with the largest depth 3 cm. Accumulated distillate during 10 hours from 8:00 am to 18:00 pm was 1.6, 1.35 and 1.05 L/m<sup>2</sup>, for three perfect days 20, 22 and 24.03.2019 and for the three water depths 1, 2 and 3 cm, respectively.

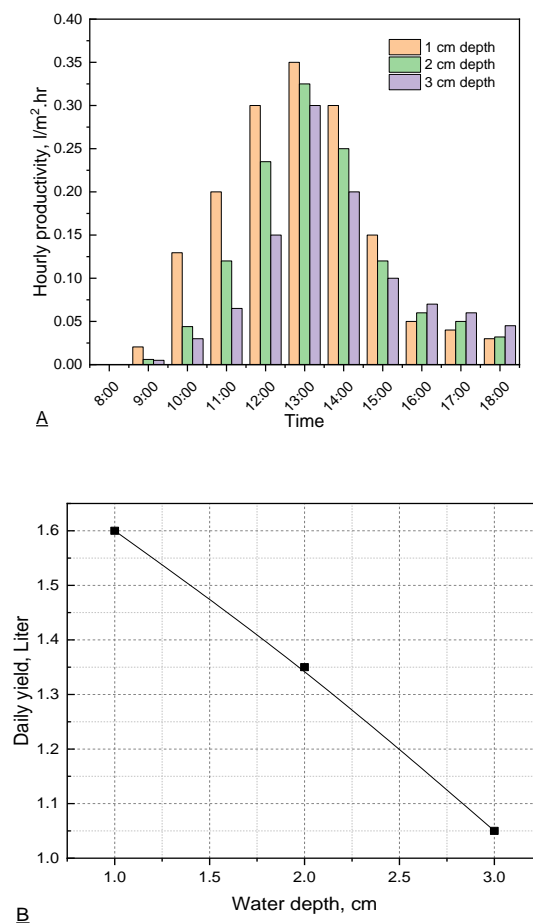


Figure 5. A- daily freshwater productivity of solar still with different basin water depth 1, 2 and 3 cm



#### 4. Estimated productivity cost

The total cost of solar still (C) is estimated from equation (1) [22]:

$$C = F + V \quad (1)$$

$$V = n \times 0.2 \times F \quad (2)$$

Where: F: fixed costs, V: variable costs, n: Life expectancy for solar stills which is 10 years

Suppose the variable cost V is 0.2 F per year; from table 1 then the total productivity cost from solar still is:  $C = 54 + 10 \times 0.2 \times 54 = 162$  \$

The daily productivity for solar still per unit area  $0.54 \text{ m}^2$  at different water depth (1, 2 and 3 cm) was 1.6, 1.3 and  $1.05 \text{ L/m}^2$  respectively, if assuming the solar still operating 300 days in the year, therefore, the total annual productivity during the work period 10 years for solar still is 4800, 3900 and  $3150 \text{ L/m}^2$ .

So the cost freshwater productivity ( $\text{L/m}^2$ ) from solar still at three different depth is  $216/4800 = 0.033 \text{ L/m}^2$  at water depth 1 cm,  $162/3900 = 0.041 \text{ L/m}^2$  at water depth 2 cm, and  $162/3150 = 0.051 \text{ L/m}^2$  at water depth 3 cm.

**Table 1.** Fabrication cost for the solar still

Type material	Quality	Cost (\$)
MDF Wooden Board 1.8 cm thickness	3 $\text{m}^2$	20
Glass cover 0.4 cm thickness	1.2 $\text{m}^2$	5
PVC type of pipe 1.5 cm diameter	2 m	3
aluminum plate with thickness 0.09 cm	0.8 $\text{m}^2$	10
Aluminum foil with thickness with 0.03 cm	0.5 $\text{m}^2$	2
Spray paint heat-resistant	1 piece	2
Heat-resistant silicone glue	1 piece	2
Extra work accessories		10
Total cost		54 \$

#### 5. Conclusion

1. The basin water with 1 cm, required less time to evaporate, but it quickly loses the thermal energy, while the higher depths more than 1 cm storage thermal energy for a longer period with high potential energy, especially at sunset times.

2. The productivity of solar still with depth at 1 cm started early in comparison with two depths 2 and 3 cm, the productivity ratio ranged from 240% at 9:00 am to 60% at 11 am. Afternoon the production ratio reduced to reach at the end day 18.5% in comparison with 2 cm depth, and 52% in comparison with 3 cm depth.

3. The best saltwater depth for the best freshwater productivity is 1 cm. However, saltwater depth less than 1 cm is not recommended as much salt build-up is expected in the base basin based.

4. In general, the estimated production cost of one liter of freshwater form single slope solar still model is 0.033 \$, 0.041 and 0.05 \$ at depths 1, 2 and 3 cm respectively. Thus, the cost of production decreases as the depth of water decreases.

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